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A New Class of Binary Stars. By Professor Edward C. Pickering.

A study of the photographic spectra of the stars undertaken as a memorial to Dr. Henry Draper has been in progress for several years at the Harvard College Observatory. This has led to the detection of certain binary stars whose components are too close to be separated by ordinary means. Suppose the two components of such a binary to have similar dimensions and identical spectra, and to revolve around each other in a circular orbit whose plane passes near the Sun. When the stars are in conjunction both are moving perpendicular to the line of sight, their spectra will be superposed, and it will be impossible to distinguish them from a single star. After making a quarter of a revolution or at elongation, however, one star will be approaching the observer rapidly, and all the lines in its spectrum will accordingly be moved slightly towards the blue end of the spectrum. The other star will be receding and its lines will be carried towards the red end. The two spectra will thus be separated so that every line will appear double. After another quarter of a revolution the motion will again be perpendicular to the line of sight and the lines will be single. At the next elongation the lines will be again double, but reversed, so that the star which was before approaching is now receding.

The occasional doubling of the K line in the spectrum of ζ *Ursæ Majoris* has already been announced. A careful study was made of this star last autumn. In all 113 photographs have been obtained on 80 nights. These seem to show that the lines became double at intervals of 52 days, corresponding to a period of revolution of 104 days. It now seems probable that the period should be reduced one half. Owing to the low altitude of the star the first photographs were often poor, but now that it rises higher during the night the law regulating the phenomenon will soon be determined. The spectrum is that of the first type in which the principal lines are those due to hydrogen, and are too broad to permit a slight separation to be detected in them. The other lines, except the K line, are very faint, and when double are seen with difficulty. The best photographs, however, show that several of these also are double, the separation being proportional to the wave-length of the line. The maximum separation of the K line somewhat exceeds 0·2 millionth of a millimetre, corresponding to a relative velocity of one star compared with the other of about a hundred miles a second.

A similar case has been discovered by Miss A. C. Maury, who is making a careful study of the spectra of the brighter stars. The star β *Aurigæ*, from 47 photographs on 30 nights, shows a distinct doubling of its lines at intervals of almost exactly two days, indicating a period of revolution of four days. The lines

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are therefore alternately single and double on successive nights. The first indication of the doubling of the lines is that they become hazy, and the change is so rapid that it can sometimes be detected in successive photographs or in the two edges of the same spectrum. The width of the photographed spectrum, as explained elsewhere, is due to the gradual progress of the actual spectrum over the plate, in consequence of an intentional difference between the rate of the clock and the diurnal motion.

The type of spectrum resembles that of ζ *Ursæ Majoris*, but the hydrogen lines are finer, and the faint lines are better shown. About one hundred and fifty lines in all are visible when single, and in some photographs about a dozen of the more marked lines can be seen to be double, the others becoming hazy or invisible. The maximum separation of the K line is about 0·3 units, or three millimetres on the scale of the map of Ångström. The corresponding velocity is about one hundred and fifty miles per second. Hence it may be inferred that the distance of the two stars is about eight millions of miles, and that their total mass is 2·3 times that of the Sun. In other words, if two stars, each having a mass about one-fifth greater than that of the Sun, were placed eight millions of miles apart, and were made to revolve in a circular orbit, the observed phenomenon would be produced. The velocity here given is that of the component of the motion parallel to the line of sight. If the plane of the orbit does not pass through the Sun, the total velocity, radius, and masses will be proportionately increased.

The analytical conditions for determining the exact form of the orbit are comparatively simple. In the formulæ for elliptic motion it is only necessary to place the differential coefficient of the component of the motion parallel to the line of sight equal to the separation, and discuss its variation with the time. The results are reduced to absolute distances by the usual formula. (See *Proc. Amer. Acad.* xvi. 8.) If the orbit is circular the curve is that of sines. If elliptic, with the major axis directed towards the Sun, the maximum separation of the lines will not occur midway between the times at which the lines are single. If the major axis is perpendicular to the line of sight, the alternate separations will vary in amount, and the time required for any line to become single will be alternately long and short. This last case seems to be represented by ζ *Ursæ Majoris*, while the orbit of β *Aurigæ* seems to be nearly circular.

In β *Aurigæ* the more refrangible of the two components of the K line appears to be generally the more intense of the two, instead of becoming alternately brighter and fainter as might be expected if due to a real difference in the spectra of the two components. This is perhaps due to additional faint lines of somewhat shorter wave-length than K.

No satisfactory measurement has as yet been made of the parallax of β *Aurigæ*. We may, however, compare it with α *Aurigæ*, whose parallax, according to Dr. Elkin, is 0″·11. The

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proper motion of *α Aurigæ*, according to Auwers, is 0″·43, of *β Aurigæ* 0″·07. The ratio of the light is as 5·7 to 1. Accordingly, if *α Aurigæ* was removed to 6 times its present distance its proper motion would be about that of *β Aurigæ*; while if its distance was increased 2·4 times the brightness of he two stars would be about the same. This last quantity should probably be further increased owing to the greater intrinsic brightness of *β Aurigæ*. Estimates of distance based on these facts are of course uncertain, but they do not encourage us to anticipate a greater parallax for *β Aurigæ* than 0″·05. The maximum separation of the components would then be 0″·004. The maximum separation of the lines in the spectrum is about 20″. Accordingly in this case the spectroscope may be said to make the apparent angle of separation about 5,000 times as great as it would be without the aid of the prism. If a binary star was found, one of whose components appeared to describe in four days an orbit of the size of the disc of *Jupiter*, we should regard it as a remarkable object. Yet this is the scale of the apparent motion of the components of the lines of the spectrum.

No binary star has hitherto been discovered having a period less than several years. The presence of dark bodies revolving in a few days around variable stars of the Algol type, however, indicates a phenomenon resembling that here described.

In view of the great velocity of these stars it might be thought that even a rare resisting medium would be sufficient to convert their energy rapidly into heat. Probably, however, such a medium would revolve with the stars, and its effect would therefore be small. There is no evidence of a change in brightness of *β Aurigæ* during the last two thousand years, as is shown by the following determinations of its light (*H. C. Annals*, xiv. 145): Ptolemy, A.D. 138, mag. 2·1; Sûfi, A.D. 964, mag. 2·0; W. Herschel, 1795, mag. 1·9; J. Herschel, 1835, 2·3; Harvard Photometry, 1880, mag. 2·1. The corresponding magnitudes for *ζ Ursæ Majoris* are 2·1, 2·0, 2·2, 2·2, and 2·4.

It is needless to add that the investigation is still in progress. Additional photographs are being taken, and a complete discussion will appear later. Similar changes are also suspected in several other stars. Photographs are accordingly taken of them at short intervals.

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γ Coronæ Australis. By E. B. Powell.

The orbit for *γ Coronæ Australis* now submitted has been derived by the graphical method laid down by Sir John Herschel. The accordance between observation and calculation seems pretty fair, except in the case of the later distances; these imply that the distance is increasing, but there appears no doubt of its being on the decrease. By calculating the sectorial areas, the annual sector afforded by past observations does not differ much from ·087 of a square second; but the Windsor (Australia) measures give an area much in excess, indicating that the distances for 1887 and 1888 are very considerably greater than they should be. At the same time, as the agreement between observation and calculation is mainly for the north preceding side of the perspective ellipse, it is possible the apparent orbit does not possess *quite* sufficient width, but turns the southern end *somewhat* prematurely. If this be so, the projected centre of the orbit will be thrown more on the following side, and the position of the periastron will require to be a little advanced. Also, as the method pursued in arriving at the orbit draws some of the elements from a, the position-angle of the periastron, it may be found necessary to modify the dependent elements to a slight extent.

The period and the time of periastron passage were obtained from six equations of mean motion: the separate results were very fairly harmonious, the mean value of P not differing from the extremes by more than about half a year, and the mean value of T differing still less from its extremes.

The orbit agrees fairly well with the measures of Herschel, Jacob (excepting for the epoch 1850·46), and Schiaparelli. The greatest angular discrepancy, $+2^\circ\cdot1$, attaches to my own measure for 1870·1, which, as mentioned in my paper published in the *Monthly Notices*, No. 1, for November 1883, was the result of observations taken with an eyepiece of low power, my usual eyepiece having been lost. It seems there is greater difficulty generally in measuring the distance than in taking the angle of position of the star. This I experienced with my 5-foot equatoreal carrying a 4-inch object-glass. The smallness and the equality of the components enable an observer to lay a spider-line pretty accurately across their centres; but, without a tolerably high power, it is far from easy to measure the distance satisfactorily. In my own case the distance was beyond my telescope, and I never did more than make an estimate of it. If I might be allowed, I would suggest that two or three observers possessing powerful telescopes should give attention just now to this binary. The comes is running in to its smaller minimum distance, $1''$ or a little more, and careful measures would enable a really excellent orbit to be deduced after the lapse of a few years.

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